

NANOMEDICINE – THE FUTURISTIC MEDICINE

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ABSTRACT

The use of nanotechnology in medicine offers exciting possibilities and while some techniques are only being imagined, others are at various stages of development and testing, and still others are in actual use. Use of nanotechnology in medicine, called “Nanomedicine”, involves application of nanoscience and nanotechnology in the use and manufacture of nanodevices that can work at cell level. This area when fully developed will revolutionize the medical field.

This article reviews the possible influence of the emerging nanotechnology discipline on healthcare with the objective to enhance awareness of the readers about the nanotechnology implications for the 21st Century medicine. As the nanoscience changes from concept to a discipline, so does the nanomedicine that integrates the nanotechnology into medicine for DNA sequencing, diagnosing, monitoring, healing, tissue regenerating, and even reversing the disease process.

KEYWORDS: Nanomedicine, Nanotechnology, Dna, Futuristic Medicine, Prosthetics, Imaging, Nanobots, Tissue Regeneration, Diagnosis, Monitoring

INTRODUCTION

“Nanomedicine is manipulation of biology at the nano scale in vivo and develop new technologies, and engineer devices and hybrid structure for repairing tissues as well as preventing and curing diseases”¹

“Nanomedicine is inventing new ways to fight cancer, heal wounds and pilot drugs into the cells”²

Nanotechnology, the manipulation of matter at the atomic and molecular scale to create materials with remarkably varied and new properties, is a rapidly expanding area of research with huge potential in many sectors, ranging from healthcare to construction and electronics. In medicine, it promises to revolutionize drug delivery, gene therapy, diagnostics, research, development and clinical applications. The prefix "nano" stems from the ancient Greek for "dwarf" (Dictionary.com). In science, it means one billionth (10 to the minus 9) of something; thus a nanometer (nm) is one billionth of a meter, or 0.000000001 meter. A nanometer is about three to five atoms wide, or some 40,000 times smaller than the thickness of human hair. A virus is typically 100 nm in size.

Growing interest in the future medical applications of nanotechnology is leading to the emergence of a new field called **nanomedicine**. Nan medicine needs to overcome several challenges of its medical applications to improve understanding of path physiological basis of disease, bring more sophisticated diagnostic opportunities, and yield more effective therapies and preventive properties.

A DNA molecule, about the size of 2.50billionth of a meter (2.5 nm), holds the entire code of life. Scientists now have achieved the ability to create devices of that size paving the way for pushing medicines into the cells and new way of

diagnosing diseases. Nan science and nanotechnology are undergoing rapid exponential growth and many applications that will result are not yet even evident. This brief review suggests opportunities of their use in the medicine leading to new possibility of diagnosis and cure by highlighting some major medical areas in which nanotechnology has shown promise.

Bone Healing

Nanotechnology and its attendant techniques have yet to make a significant impact on the science of bone healing. However, the potential benefits are immediately obvious with the result that hundreds of researchers and firms are performing the basic research needed to mature this nascent, yet soon to be fruitful niche. Together genomics and proteomics combined with tissue engineering is the new face of orthopedic technology³. Nanotechnology has also been greatly utilized for bone tissue engineering and employed to overcome some of the current limitations associated with bone regeneration methods. This includes insufficient mechanical strength of scaffold materials, ineffective cell growth and osteogenic differentiation at the defect site, as well as insufficient production of growth factors to stimulate bone cell growth⁴. Gu, et al., (2013)⁵ have summarized highlights of the recent advancements of nanostructured particles and scaffolds for the treatment of bone cancer metastasis, osteosarcoma, bone infections and inflammatory diseases (e.g., osteoarthritis) as well as for bone regeneration. Weitzmann et al., (2015)⁶ have also reported that *in vitro*, engineered 50 nm spherical silica nanoparticles promote the differentiation and activity of bone building osteoblasts but suppress bone-resorbing osteoclasts.

Smarter Bandage

New nanomaterials will not simply cover wounds, but also alert doctors to problems and deliver drugs⁷. These bandages contain some special dyes that react to different oxygen levels, and with added nano-sized molecules control the dye activity to indicate health of the wound it covers. The bandage changes color like a traffic light from green, through yellow, orange and red depending upon the amount of oxygen present. The bandage will appear green, if wound tissue is bathed in oxygen and is healthy. But areas of the wound that are oxygen-starved, would show patches of yellow, orange and finally an alarming red color.

Nanoparticles and Cancer

Cancer plays a deadly game of hide and seek in the body⁸ and the drugs have trouble in distinguishing between the healthy and tumor cells causing miserable side-effects while leaving the cancer cells unaffected. The immune system deeming the cancer drugs as foreign, like bacteria, may break these down rendering them ineffective. The drugs that do manage to arrive the tumor may become entangled in the dense growth of the malignant mass and unable to penetrate effectively. Recent advances in nanomedicine are allowing drugs to hit the tumors by crafting the drug vehicle or wrapping in a protective cover shell that shuttles chemotherapy drugs through the body landscape to the tumor. Besides navigating the drug to the target site, the nanodevices do not trigger the immune system alarm.

Short drug circulation times and difficulty in localizing therapy to tumor sites are but two of the challenges associated with the existing cancer treatments. More troubling are the issues of drug toxicity and tumor resistance. Toxicity can cause major complications, such as low white bloodcell counts or heart failure that necessitates cessation of the treatment. The tissue damage inflicted by some therapies can even be fatal. And evolution of drug resistance by tumors accounts for the vast majority of cases in which treatment fails. Given these and other issues associated with treatment safety and efficacy, scientists are making tremendous efforts for the utilization of nanomedicine in the fight against cancer⁹.

⁸. Japanese researchers have developed adaptable nanocapsules that can help in the diagnosis of glioblastoma cells – a highly invasive form of brain tumor¹⁰. These nanocapsules bind to membrane receptors that play a significant role in the formation of new blood vessels in tumors, making them a good tumor tracer.

Nanobots

These are tiny therapeutic agents that smartly navigate under their own power to a specific target anywhere in the body. On arrival these self-guided machines, may act in any number of ways – from delivering a medicinal payload to providing real-time updates on the status of their disease fighting progress. After having achieved their mission, they safely biodegrade, leaving little or no trace behind¹¹. Overcoming all technical challenges may take 20 years or more, but the first step towards a remote-controlled medicine has already been taken. One of the greatest challenges is making the nanodevices get to their targets in the body. Use of magnetic fields for nanodevices made from iron or nickel and ultrasound waves by directing them at medicine containing nano-bubbles that can burst once in the target site and force the medicine into the site are the leading candidates for guiding the nanodevices to their destinations. The magnetic approaches by attaching the iron oxide nanoparticles to the individual stem cells and guiding them to the broken bone sites in animals have shown potential¹².

The autonomous “micro motors” or “Nanomeds” (tiny molecular machines that remain inert in the body until they detect a cell damage which triggers their activity) can resolve the issue of external guidance required for the magnetic and ultrasonic guided devices for the delivery of the therapeutic cargo¹¹. The Nanomeds would rely on chemical reactions for propulsion, such as oxidizing a glucose molecule that can generate energy; even more promising propositions are the naturally occurring substances, such as stomach acid and water, occurring abundantly in the body.

Advanced Prosthetics and Therapeutic Implants

Nanotechnology is enabling new advances in light weight prosthetics, neuro- and sensory- prosthetic devices with advanced distribution, controls and feedback and assists the critical function devices, such as cardiac pacemakers. It has a potential use in neuro-stimulation, cochlear implants, and vision prosthetics requiring low energy. Nanotechnology is a key input for the tiny implant sensors for measuring pH, temperature, glucose and other physiological parameters which can report data wirelessly to understand physiological function and disease process, thus contributing to medical diagnosis and monitoring the chronic diseases, like diabetes, cancer, etc. Such active implants can also deliver insulin or other therapeutic medications^{13, 14, 15}. Several products have been created and tested that help reduce infections caused by implantable medical devices. Some of these products use silver nanoparticles that fight microbes by slowly releasing silver ions that are toxic to bacteria and other microbial pests. The surface of implantable medical devices can be coated with silver nanoparticles, and the slow release of silver ions helps keep the area of implantation free of infection¹⁶. Similarly neural prostheses are currently being researched using nanotechnology as a means of supplementing or re-establishing lost neurological functions for persons suffering brain injuries in order to significantly improve their quality of life. One such advancement is carbon nanotubes (CNTs) that have paved its way into the biomedical field as a potential material for neural prosthetics due to their higher physical, electrical, and mechanical properties than the traditional materials such as silicon and ceramics¹⁷.

Drug Delivery

Nanosized particles are optimized for absorption of drugs through inhalation therapy and are specially adapted for

the delivery of non-soluble and hydrophobic drugs. The nanosized particles can deliver drugs in several novel ways. The encapsulation strategies can include absorption of drugs, and coordination of compounds bonded covalently, which can be selectively released at the target sites by controlling pH (pH levels of tumors are lower than the normal tissue). The nanoparticle surfaces could be used to carry the antibodies to the tumors and then releasing them through raising temperature accomplished by electromagnetic radiation or light. Nano-particulate steroids have been introduced into blood cells and when the cells die of natural deaths, the steroids are released into the body in tiny doses thus avoiding the harmful side effects. Since nano-particulate pharmaceutical agents can penetrate cell membranes effectively, they can cross the blood-brain barrier. Through them a variety of Trojan horse techniques can be used to pass the defensive gates of blood-brain barrier and some other barriers of the body¹². Various advantages of nanoparticles for the drug delivery include control of pharmacokinetics, variable payload capacity, multiple affinity effects, combination of therapy effects, and Trojan horse effects¹⁸. The drug delivery nanoparticles could be albumin-based, colloids, emulsions, gels, fibers, nanotubes, polymers, gold, or carbonnanoparticles and their payloads could be delivered into tumors by taking advantage of the pathophysiological conditions, such as the enhanced permeability and retention effect, and the spatial variations in the pH value. Additionally, targeting ligands (e.g., small organic molecules, peptides, antibodies, and nucleic acids) have been added to the surface of nanoparticles to specifically target cancerous cells through selective binding to the receptors over expressed on their surface¹⁹.

Nanotechnology and Imaging

Nanoparticles can be used to capture and enhance the medical images for medical diagnosis with x-rays, computed tomography (CT), magnetic resonance imaging (MRI), optical coherence tomography (OCT), confocal reflectance, wide-field optical, fluorescent microscopy, infrared (IR) and ultrasonic imaging, especially for contrast enhancement of images in soft tissues²⁰. Hence, they are very useful in the diagnosis of cardiovascular, cancer and neurological diseases and disorders. Gold nanoparticles have been in active use in the identification of chemical and biological agents. Electron microscopy (predominantly, transmission electron microscopy — TEM) has historically remained the predominant means to detect bio specific interactions using colloidal gold particles due to their high electron density²¹.

The nanoparticles provide several advantages over the traditional imaging compounds as besides providing higher density of contrasts, they can bind to specific cells increasing sensitivity of their detectability. In addition to imaging, nanoparticles can be used to deliver targeted energy to kill pathogenic cells by absorbing or generating heat when irradiated with infrared light or exposed to ultrasonic radiation. Wireless endoscopy capsules are self-contained ingestible cameras that can transmit images from within the gastrointestinal tract. Recently²² Cheng et al. (2015) have reported development of *multifunctional* nanoparticles with additional capabilities, like targeting and image contrast enhancements.

Nanotechnology in Diagnosis's and Medical Monitoring

Medical diagnosis depends on detailed observation and nanotechnology provides the ability to observe details at the cell scale and biological molecules opening up new possibilities for diagnostic micro-sensors with new and specific capabilities²³. The new sensors are based on:

- Smaller size
- little power requirement

- More sensitivity
- More selectivity
- Wireless operation
- Biocompatibility

The nanotechnology devices could be used in the medicine for^{24, 25};

- Diagnosing and monitoring diseases and disorders in clinical research and epidemiology.
- Genetic analysis and screening based on rapid and inexpensive DNA sequencing capabilities which can be combined with system biology and targeted nanomedicine, as new possibilities of personalized medicine.
- Personal health monitoring based on wearable and implantable wireless devices for clinical and ambulatory use, providing improved patient health management everywhere from intensive care unit to patient's home, work, and even recreational environment.

Biomedical engineers are developing tiny, implantable monitors that could help treat patients with chronic conditions, such as heart diseases or diabetes. These devices can send data wirelessly from key regions of the body or blood to external receivers. They not only monitor the conditions but may also take corrective actions to save lives of patients²⁶.

Nanoparticles for Tissue Regeneration

Nanotechnologists have become involved in regenerative medicine via creation of biomaterials and nanostructures with potential clinical implications and the objective to develop systems that can mimic, reinforce or even create *in vivo* tissue repair strategies. And the recent advances focus on the application of nanotechnology in tissue engineering to restore skin, cartilage, bone, nerve, and cardiac tissues²⁷. Biomaterials for tissue regeneration replace inert materials with bioactive compounds capable of eliciting controlled actions and reactions to stimulate and guide cell growth and help the body heal itself. They include glasses, ceramics, glass-ceramic, and polymers. They pave the way for the development of cost-effective therapies for *in-situ* tissue regeneration, guidance of tissue growth, and halting or even reversal of pathological processes and thus are a great tool to initiate and control regenerative process by fabrication of scaffold and delivery of signaling molecules and stem cells. Researches are underway in using the nanotechnology for developing intelligent bioactive materials to serve a growth support vehicles, an ultimate vision of development of implantable, cell-free, intelligent, bioactive materials that would provide signaling and stem-cell therapy into a single, unified, nanotechnology-based therapy. In regenerative medicine, nanosized gold particles have been reported to promote differentiation of human mesenchymal stem cells into osteoblasts^{28, 10}. Nanostructured scaffolds that mimic the tissue-specific microenvironment are of great interest in nanotechnology for tissue engineering and regenerative medicine because of their mechanical and electrical properties similar to those of native tissues that enhance cell adhesion, proliferation, differentiation, and even maturation, thereby fostering cell function and tissue growth²⁹.

Nanotechnoly and Dna Sequencing

The technology for sequencing DNA aided by the application of advances in miniaturized automation has progressed rapidly. The DNA sequencing of entire genome that took weeks and cost several thousand dollars a decade ago now takes four hours and costs \$1000 and both the time and costs are still diminishing with the application of

nanotechnologies, such as microarrays³⁰. The most recent DNA sequencing technique is *single cell molecule method* that uses functionalized carbon nanowires. The DNA strand is passed over the nanowires and the conductivity differences between different bases can be measured allowing the intact strand to be coded sequentially. Another technique passes the DNA strand through functionalized nanopore of precise dimensions so that the electrical potential created by interaction with four different DNA bases can be distinguished³¹.

Several other uses of nanotechnology in medicine includes protein filled nanoparticles that stimulates immune responses and could be used in inhalable vaccines for flu and pneumonia³²; in blocking malarial parasites from spreading to new blood cells³³, and absorb toxins from blood stream²⁵.

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